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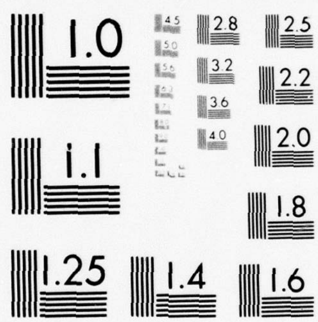

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THE AGGREGATE PILOT PIPELINE MODEL

Jon M. Knight

Technical Report - AFIT TR 78-6
November 1978

School of Engineering
Air Force Institute of Technology
Wright-Patterson Air Force Base, Ohio

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ABSTRACT

This Technical Report documents the structure of an aggregate representation of a system which governs the recruitment, training, and allocation of Air Force pilots. While the model is highly simplified, it captures many of the essential policies and decisions which generate the dynamic behavior of the overall system. Specifically, the model takes as given the authorized flying hours and aircraft available to the Air Force; it combines these data with information about projected strength levels in the pilot force to determine training requirements. These training requirements are used to establish the requirements for Undergraduate Pilot Training (UPT) instructors and recruiting quotas. The model then allocates the existing force among three categories: (1) the active mission force, (2) UPT instructors, (3) the rated supplement. The model can be used to examine such things as overall policies controlling UPT instructor force size, information usage in the determination of UPT class size, and allowable limits of variation on the UPT instructor to student ratios. It also can be used to test the sensitivity of system adjustment process to exogenous impacts.

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Chapter 1
Methodology

This model represents the Air Force Pilot pipeline as a closed loop feedback control system using the Systems Dynamics approach developed by Forrester [1]. Specifically, it uses linked series of nonlinear first order differential equations to describe the system structure. The system is transformed into a computer program written in DYNAMO III, and a particular numerical solution is obtained by applying a Cauchy integration routine over a specified period of time.

This methodology was applied to this problem because it facilitates both the model formulation and testing process. The pilot pipeline system is readily described as a continuous flow closed loop feedback system. The mathematical model derived can be directly rendered into the form of a DYNAMO program, and the DYNAMO simulation language is easily manupilated in the interactive mode for modification and analysis.

Figure 1 shows the basic flow diagram symbols that will be used to represent components of system structure.

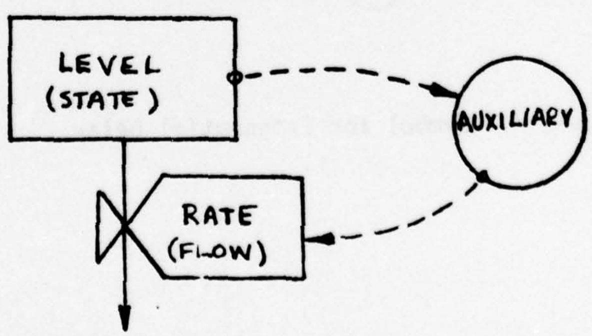

Figure 1. Flow Diagram Symbols

Rectangles will represent levels, or states in the system. The "valve" symbol will represent a computation or decision about a particular rate of flow through an action channel in the system. Circles are points where information is transformed for rate computations, and broken lines are information flows. Other special symbols include those shown in Figure 2. The segmented rectangle is a third order exponential filter (delay) of an input flow. The "cloud" symbol is a source or sink that does not affect the behavior of the system.

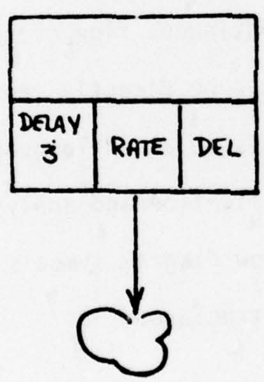

Figure 2. Symbol for Exponential Delay

Chapter 2

Basic Model Structure

In order to focus on the central features of the model, the description begins with the state variables being controlled by the system. There are three crucial levels represented:

(1) The number of active mission pilots (AMP).

(2) The size of the rated supplement (RSUP).

(3) The size of the UPT instructor force (INS).

The current value of any state can be described in terms of its initial value, plus the net of inflows and outflows to the state between the initial time and the present. For instance, in this model the active mission pilot force depends upon its initial value plus all UPT graduates (MPG) minus attrition (ATTM) minus all net flows to the rated supplement (SUPASGN) and to the instructor force (INASGN) since the initial time point. In integral equation form this would be

$$\mathrm{AMP}(t) = \mathrm{AMP}(0) + \int_0^t [\mathrm{MPG}(t) - \mathrm{INASGN}(t) - \mathrm{SUPASGN}(t) - \mathrm{ATTM}(t)]\,dt$$

DYNAMO uses the following notation to represent the same equation:

AMP.K = AMP.J + DT * (MPG.JK - INASGN.JK - SUPASGN.JK - ATTM.JK)

Here the timescript K indicates the current time period. J represents the previous time point of state evaluation. JK is the interval between J and K during which flow rates occurred, a timescript KL would indicate a flow rate computed for the next increment of time. The length of the increment is fixed at some finite DT (see Figure 3). A numerical

solution begins with an initial value for AMP(0) and uses the computer program to evaluate the equation system over a series of steps of equal length to obtain state variable trajectories. In flow diagram form the basic state variables and flow rates are represented in Figure 4. In the sequel, the equation numbers correspond to the numbers in parentheses on the flow diagram.

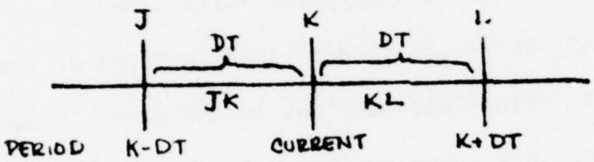

Figure 3. DYNAMO Timescript Conventions

The level of qualified pilots actually involved in flying aircraft is given by

(1) L AMP.K=AMP.J+DT*(MPG.JK-ATTM.JK-INASGN.JK-SUPASGN.K)

(1.1) N AMP=AMPI

(1.2) C AMPI=13250

This equation was explained above.

The set of pilots in the Air Force working in jobs not directly involved in flying is the rated supplement. Its value is computed as

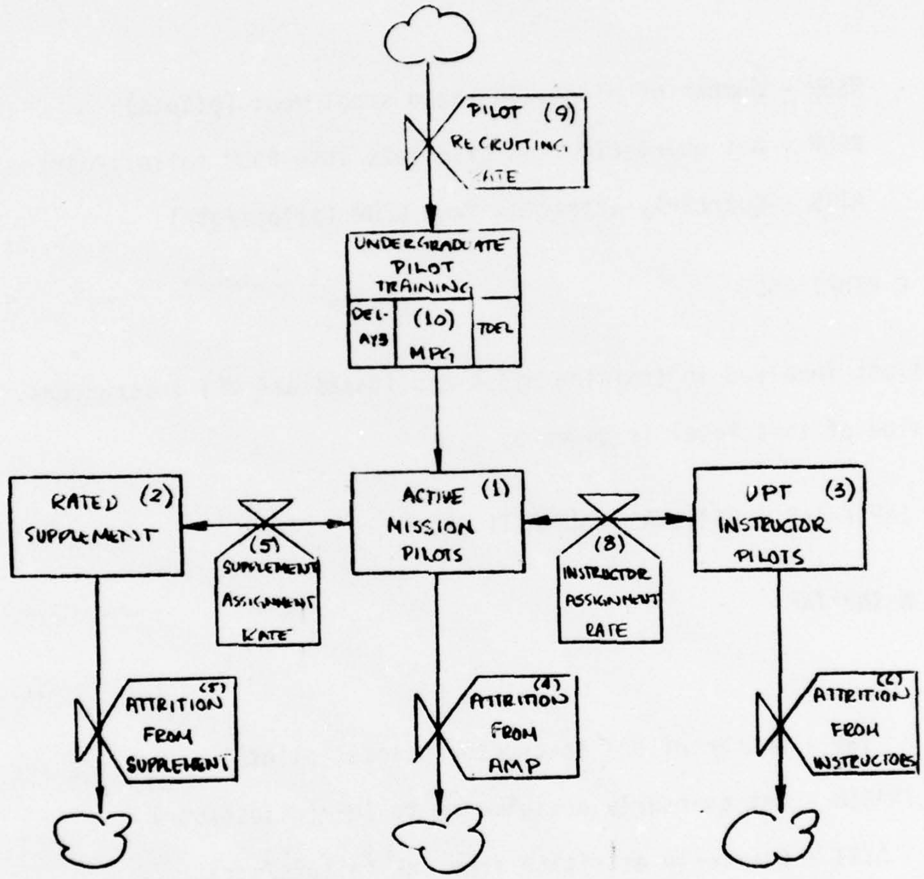

FIGURE 4. BASIC LEVELS AND RATES

(2) L RSUP.K=RSUP.J+DT*(SUPASGN.JK-ATTS.JK)

(2.1) N RSUP=RSUPI

where

RSUP - Number of pilots in rated supplement (pilots)

RSUP - Net quarterly flow of pilots into RSUP (pilots/qtr)

ATTS - Quarterly attrition from RSUP (pilots/qtr)

(2.2) C RSUPI=2500

The pilots involved in training pilot candidates are UPT instructors. The value of this level is given by

(3) L INP.K=INP.J+DT*(INASGN.JK-ATTI.JK)

(3.1) N INP=INPI

where

INP - Number of UPT instructor pilots (pilots)

INASGN - Net quarterly assignments to INP (pilots/qtr)

ATTI - Quarterly attrition from INP (pilots/qtr)

(3.2) C INPI=500

Given that we have the basic levels in the system designed and valued for some initial time point, we must then be able to compute the values of variables which cause changes in the system states. There are two basic types of variables involved in state change. First are those variables completely specified by policy as a response to the

internal state of the system; in (1)-(3) above, these are INASGN, MPG, and SUPASGN. The second are those variables over which there is either no control or limited control. In (1)-(3), these include ATTM, ATTS, and ATTI. These variables are, for the most part, exogenously determined. Looking at the exogenous variables first, attrition from the active mission pilot force is given by

(4) R ATTM.KL=AMP.K*ATTMC*(ADMM.K)*XTEST.K(1)

where

ATTM - Quarterly attrition rate from mission force (pilots/qtr)

AMP - Active mission pilots (pilots)

ATTMC - Normal fractional turnover (1/qtr)

ADMM - Attrition management control multiplier (unitless)

XTEST - Exogenous influences test variable

The equation assumes there is some average mean length of service which induces a normal turnover rate. This normal rate is modified by uncontrolled exogenous factors (XTEST) and by management (ADMM); ADMM is exercised when there are aggregate force overages or shortages relative to authorized strengths. Similar equations describe attrition from the instructor force and the rated supplement. The only difference is a factor which allows variable degrees of application of management control to attrition from the levels:

(5) R ATTS.KL=RSUP.K*ATTSC*(ATMS.K)*XTEST.K(2)

where

ATTS - Quarterly attrition from rated supplement (pilots/qtr)

RSUP - Rated supplement (pilots)

ATTSC - Normal fractional turnover (1/qtr)

ADMS - Attrition management control multiplier (unitless)

XTEST - Exogenous influences test variable

(6) R ATTI.KL=(INP.K*ATTIC*ADMI.K)*XTEST.K(3)

where

ATTI - Quarterly attrition from the instructor force (pilot/qtr)

INP - Instructor pilot force (pilots)

ATTIC - Normal fractional turnover rate (1/qtr)

ADMI - Attrition management control multiplier

XTEST - Exogenous influences test variable

For test runs of this model the following parameter values were specified in constant equations:

(6.1) C ATTMC=0.02/ATTIC=0.013333/ATTSC=0.02

The values in (6.2) are arbitrary but reflective of Air Force experience. The values in (6.1) are arbitrary policy specifications.

The test equations are developed as follows:

(6.2) FOR I = 1, TTEST

```
(6.3)  A XTEST.K(I)=1+STEP(H(I),T(I))+NN(I)*SMOOTH(NOISE(),NSM(I))
                 +APL(I)*SIN(6.284*TIME.K/PER(I))
                 +RAMP(R1(I),RT1(I))-RAMP(R2(I),RT2(I))
```

(6.3.1) C TTEST=8

(6.3.2) T H=0/0/0/0/0/0/0/0

(6.3.3) T T=4/4/4/4/4/4/4/4

(6.3.4) T NN=0/0/0/0/0/0/0/0

(6.3.5) T NSM=4/4/4/4/4/4/4/4

(6.3.6) T APL=0/0/0/0/0/0/0/0

(6.3.7) T PER=20/20/20/20/20/20/20/20

(6.3.8) T R1=0/0/0/0/0/0/0/0

(6.3.9) T RT1=4/4/4/4/4/4/4/4

(6.3.10) T R2=0/0/0/0/0/0/0/0

(6.3.11) T RT2=20/20/20/20/20/20/20/20

Thus, our test equation can be turned on in varying degrees by specifying non-zero values for such things as NN(I) or H(I). For NN(I)>0 we get autocorrelated random (pink) noise between 1±.5*NN(I). For H(I)≠0 we step change attrition by a factor 1+H(I). The functions 'SMOOTH', 'NOISE', and 'STEP' are internal DYNAMO functions which, respectively, give a first order exponential average of its argument, generates uniform random noise between ±0.5 and gives a sustained step of specified height at a specified time in the program run.

Attrition management is induced when there is a discrepancy between the total force and desired total force. It is computed for each rate as follows

(6.4) A FLEV.K=TOTFOR.K/(TOTFOR.K+FORCE.K)

(6.4.1) A ADMI.K=TABHL(TAI,FLEV.K,.52,.5)

(6.4.2) A ADMM.K=TABHL(TAM,FLEV.K,.5,2,.5)

(6.4.3) A ADMS.K=TABHL(TAS,FLEV.K,.5,2,.5)

(6.4.4) T TAM=.5/1/1.5/2.0

(6.4.5) T TAI=.25/1/1.25/1.5

(6.4.6) T TAS=.30/1/1.5/2.0

where

FLEV - Attrition adjustment signal

TOTFOR - Total force

FORCE - Force discrepancy

SMT - Smoothing time

ADMI - Adjustment in attrition

Rates fully controlled by management policy to maintain a desired force allocation among AMP, RSUP, and INP are: (a) the net flow of pilots between AMP and RSUP; (b) the net flow of pilots between AMP and INP and; (c) the output of UPT. These rates are computed by equations (7)-(9). The first is designated by SUPASGN. It is a net

flow rate and may be positive or negative depending upon the direction of force imbalance. In DYNAMO, the equation is:

(7) R SUPASGN.KL=CLIP(SS.K,MAX(SS.K,0),RSUP.K,SSS)

where

SUPASGN - Net quarterly flow to RSUP (men/qtr)

SS - Desired flow to the RSUP (men/qtr)

RSUP - Pilots in the rated supplement (men)

SSS - Minimum manning in the rated supplement (men)

(7.0.1) C SSS=500

This means that

$$\text{SUPASGN.KL} = \begin{cases} \text{SS.K} & \text{RSUP.K} \geq \text{SSS} \\ \text{MAX(SS.K,0)} & \text{RSUP.K} < \text{SSS} \end{cases}$$

so that we quit assigning people back to the cockpit when the RSUP falls below some critical value. This reflects an assumption that there are some rated supplement positions more important than any rated duties. The crucial variable in this equation is clearly SS; it is computed as

(7.1) A SS.K=((DRTSUP.K-RSUP.K)/ASGDEL)+SMOOTH(ATTS.JK,AS)

where

SS - Desired flow to rated supplement (pilots)

DRTSUP - Desired rated supplement (men)

RSUP - Actual rated supplement (pilots)

ASGDEL - Time to adjust for discrepancy (qtrs)

ATTS - Attrition rate from rated supplement (pilots/qtr)

AS - Attrition averaging constant (qtrs)

(7.1.1) C ASGDEL=.3

Thus, our decision is to assign enough pilots to rated supplement duty to make up for an average of past attrition rates and to adjust any discrepancy between the actual rated supplement and the desired level over an interval of length ASGDEL. The interesting variable in this equation is DRTSUP, the desired rated supplement; DRTSUP is the difference between the number of pilots in flying or rated supplement duty and the number of spaces available for mission pilots:

(7.2) A DRTSUP.K=PILOTS.K-SEATS.K

where

DRTSUP - Desired rated supplement (pilots)

PILOTS - Pilots in active or rated duties (pilots)

SEATS - Authorized manpower spaces for pilots (pilots)

Computation of PILOTS uses the current force minus losses plus gains.

(7.3) A PILOTS.K=AMP.K+RSUP.K-(.25)*PATT.K+PMPG.K

(7.3.1) A PMPG.K=DLINF3(PREC.JK,PTDEL.K)

(7.3.2) A PTDEL.K=SMOOTH(TDEL.K,4)

where

PILOTS - Sum of active and supplement pilots (pilots)

AMP - Active mission pilots (pilots)

RSUP - Rated supplement (pilots)

PATT - Project total attrition from pilot force

PMPG - Projected UPT graduates

PTDEL - Projected training delay

The computation of authorized manpower spaces is straightforward

(7.4) A SEATS.K=PLANES.K*DCRATIO.K

where

SEATS - Authorized manpower spaces for pilots (pilots)

PLANES - Number of aircraft in flying units (acft)

DCRATIO - Desired ratio of pilots to aircraft in flying units (pilots/acft)

The authorized manpower spaces for pilots is thus computed by multiplying the number of aircraft in the force at a particular time by the desired crew ratio. The number of aircraft in the force is exogenously given; the desired crew ratio is a function of the programmed flying hours per aircraft. Thus we have:

(7.5) A PLANES.K=KACFT*XTEST.K(4)

where

PLANES - Number of aircraft (acft)

KACFT - Beginning number of aircraft

(7.5.1) C KACFT=5300

(7.6) A DCRATIO.K=TABHL(CRT,PHPA.K,0,180,30)

where

DCRATIO - Desired crew ration (pilots/acft)

PHPA - Programmed flying hours per aircraft (hrs/acft qtr)

CRT - Crew ratio table

In (7.6), DCRATIO=f(PHPA); PHPA ranges from 0 to 180 hours per aircraft quarter. CRT is the dependent variable with values at each point between 0 and 180 in intervals of 30. TABHL linearly interpolates a function between each value. Beyond the domain of the function, the extreme value is used. If we specify CRT as follows:

(7.6.1) T CRT=0/1.5/2.0/2.5/3.0/3.5/4.0

then we have a functional relationship like that in Figure 5.

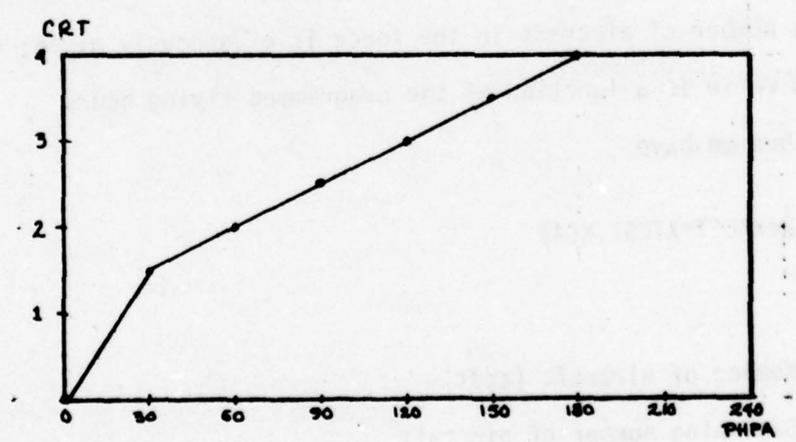

Figure 5. Desired Crew Ratio

Programmed hours per aircraft is just the Congressionally authorized flying hours divided by the number of aircraft, e.g.,

(7.7) A PHPA.K = AHOURS.K/PLANES.K

(7.8) A AHOURS.K=KHOURS*XTEST.K(5)

(7.9) C KHOURS=477000

where

PHPA - Programmed flying hours per aircraft per qtr

AHOURS - Authorized flying hours per quarter

PLANES - Number of aircraft in service

KHOURS - Normal authorized quarterly flying hours

The relationships set forth so far can be documented in graphical form as in Figure 6.

The second rate fully controlled by management is INASGN, the net flow rate into the instructor pilot force. It is superficially quite similar to (7), which computes SUPASGN, but its values come from an entirely different decision logic.

(8) R INASGN.K=CLIP(II.K,MAX(II.K,0),INP.K,III)

where

INASGN - Net quarterly flow into INP (pilots/qtr)

II - Indicated inflow (pilots/qtr)

INP - Instructor pilots

III - Minimum viable instructor pilot force

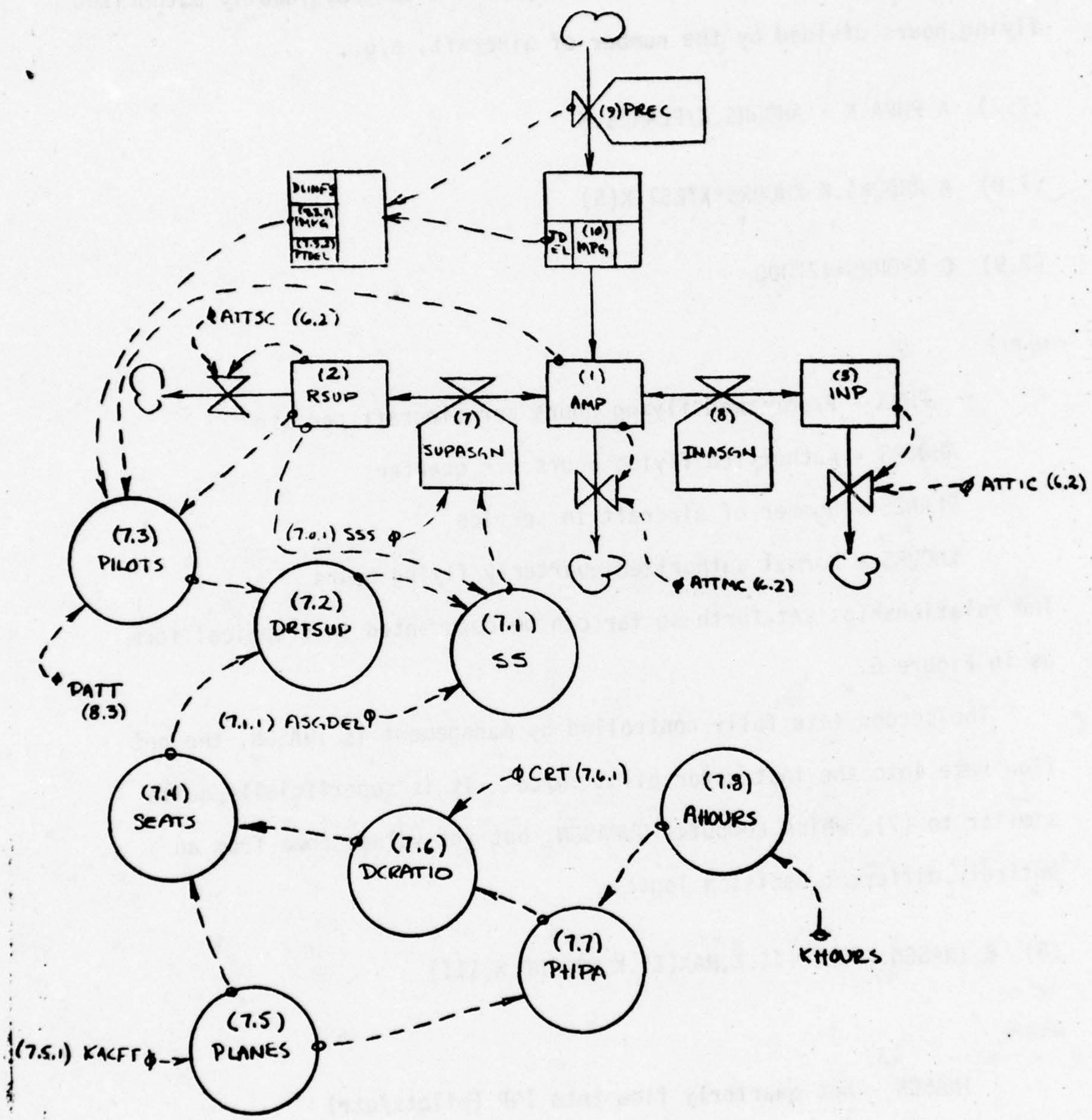

FIGURE 6: COMPUTATIONS FOR RATED SUPPLEMENT ASSIGNMENT RATE

(8.01) C III=200

Thus

$$INASGN = \begin{cases} II & INP \geq III \\ MAX(II,0) & INP < III \end{cases}$$

so that instructors are assigned at an indicated rate if INP is greater than a desired residual, but can only be assigned to the instructor force if a viability threshold is crossed. II is computed by

```
(8.1)  A II.K=(DCSIZE.K-CSIZE.K)/(ASGN.K*TPI.K)
       X + SMOOTH(ATTI.JK,IAS)
```

where

DCSIZE - Desired class size (pilots)

CSIZE - Actual class size (pilots)

ASGN - Assignment lag (qtrs)

TPI - Trainees to instructor proportionality factor

ATTI - Attrition from INP

(8.1.1) C IAS=4

This says that the indicated instructors required is an increment necessary to change the class size (at a particular trainee to instructor ratio) and make up for the expected attrition.

The desired UPT class size is an annual UPT training requirement to replace attrition, adjust any discrepancy in total force, and allign crew ratios and desired crew ratios.

(8.2) A DCSIZE.K=MAX(DSI.K,VBL)

(8.2.1) C VBL=400

(8.2.2) A DSI.K=PATT.K+(DCRATIO.K-CRATIO.K)*PLANES.K

X + FORCE.K

where

DCSIZE - Desired class size (pilots)

PATT - Projected pilot losses (pilots)

DCRATIO - Desired crew ratio (pilots per acft)

CRATIO - Crew ratios (pilots per acft)

PLANES - Number of aircraft (acft)

FORCE - Total force discrepancy

VBL - Minimum viability UPT throughout

Projected attrition is an exponential smooth of aggregate pilot losses:

(8.3) A PATT.K=4*SMOOTH(ATTI.JK+ATTM.JK+ATTS.JK,PST)

where

PATT - Projected attrition (pilots/year)

ATTI - Instruction attrition (pilots/qtr)

ATTS - Supplement attrition (pilots/qtr)

ATTM - Mission pilot attrition (pilots/qtr)

PST - Projection smoothing time (qtr)

(8.3.1) C PST=4

The crew ratio is the ratio of active pilots to active aircraft:

(8.4) CRATIO.K=AMP.K/PLANES.K

where

CRATIO - Crew ratio (pilots per acft)

AMP - Active mission pilots (pilots)

PLANES - Active aircraft (acft)

The force discrepancy variable is computed by assuming that we initially have the correct number of people on board. The force discrepancy is then the difference between the current force and the initial force values, plus an exogenous factor which represents, say, Congressionally mandated changes in the pilot force.

(8.5) A FORCE.K=(AMPI+RSUPI-AMP.K-RSUP.K)+(XTEST.K(6)-1)

where

FORCE - Force discrepancy (pilots)

AMPI/RSUPI - Initial pilot levels

XTEST - Exogenous input

The assignment proportionality factor for instructors is a function which compensates for high trainee to instructor ratios that may exist in UPT. It assigns instructors to INP at a rate larger than that indicated by the new inflows to UPT if the current trainee to instructor ratio is high, and less than proportionally to INP if the ratio is low. This tends to equilibrate at a point where the trainees per instructor reaches its goal.

(8.6) A TPI.K=TABHL(TTPI,TPINS.K,1.68,3.44,.44)

(8.6.1) T TTPI=3.44/3/2.47/2.12/1/68

where

TPI - Trainee per instructor proportionality factor

TPINS - Trainee to instructor ratio

The instructor assignment lag is given by

(8.7) A ASGN.K=ASGNDEL*XTEST.K(7)

(8.7.1) C ASGNDEL=3

where

ASSGN - Training lag for instructors

XTEST.K(7) induces noise or a persistent change into the time required to assign and train a UPT instructor.

A third rate that is controlled by Air Force management is the rate at which pilot candidates are recruited. The recruiting rate regulates the rate at which UPT produces graduates for active duty.

(9) R PREC.KL=.25*CSIZE.K*MREC.K*XTEXT.K(8)

where

PREC - Pilot recruiting rate

CSIZE - Annual UPT class size

MREC - Multiplier on recruiting from number desired

(9.1) A MREC.K=TABHL(TREC,.25*CSIZE.K,0,1400,200)

(9.1.1) T TREC=1/1/1/1/1/.95/.89/.82

where

MREC - Multiplier on recruiting from number desired

CSIZE - Class seats available

UPT class seats for the year (CSIZE) are regulated by the number of instructor pilots (INP) and the trainee to instructor ratio (TPINS).

(9.2) A CSIZE.K=INP.K*TPINS.K

where

CSIZE - UPT class seats available

INP - Instructor pilots

TPINS - Trainees per instructor

Since it may take some time to vary INP, rapid adjustment in UPT class size can be achieved by varying TPINS in the short run. The long run readjustment to maintain training quality comes through the assignment proportionality factor, TPI.

(9.3) A TPINS.K=TABHL(TTPIR,TT.K,0,1.75,.25)

(9.3.1) T TTPIR=0/.64/1/28/1.92/2.47/3.20/3.6/3.9

(9.3.2) A TT.K=DCSIZE.K/SMOOTH(CSIZE.K,1)

where

TPINS - Trainees per instructor

TT - Desired adjustment ratio

CSIZE - Class size

DCSIZE - Desired class size

The adjustment relationship is illustrated in Figure 7.

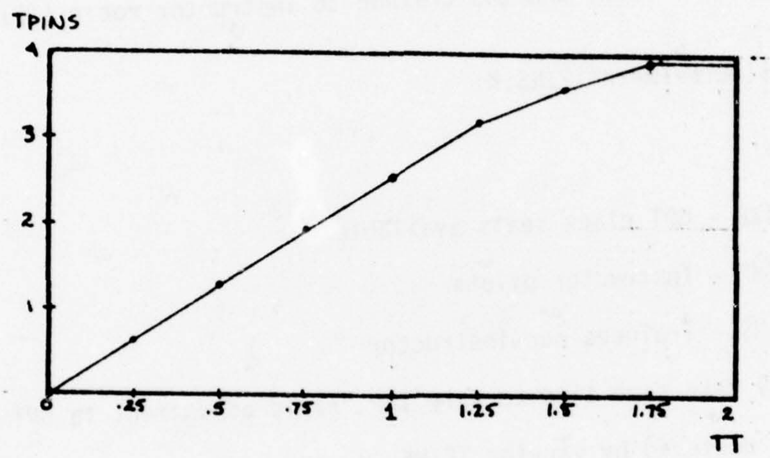

Figure 7. Trainees Per Instructor

Actual mission pilot graduates from UPT is an implicit decision depending upon previous rates of recruiting and the fraction of UPT school capacity used. As the capacity fraction increases, the training delay increases. Thus, we have

(10) A MPG.K=DELAY3(PREL.K,TDEL.K)

(10.1) A TDEL.K=CAP.K*DEL

(10.1.1) C DEL=7

where

MPG - Mission pilot graduates

PREC - Pilots recruited

TDEL - Training delay

CAP - Capacity multiplier

DEL - Normal training delay

The capacity multiplier is given by:

(10.2) CAP.K=TABHL(CAPT,CSIZE.K,0,6000,1000)

(10.2.1) CAPT=.8/1/1/1.1/1.2/1.25/1.3

Figure 8 displays the relationships from (8) - (10.2.1).

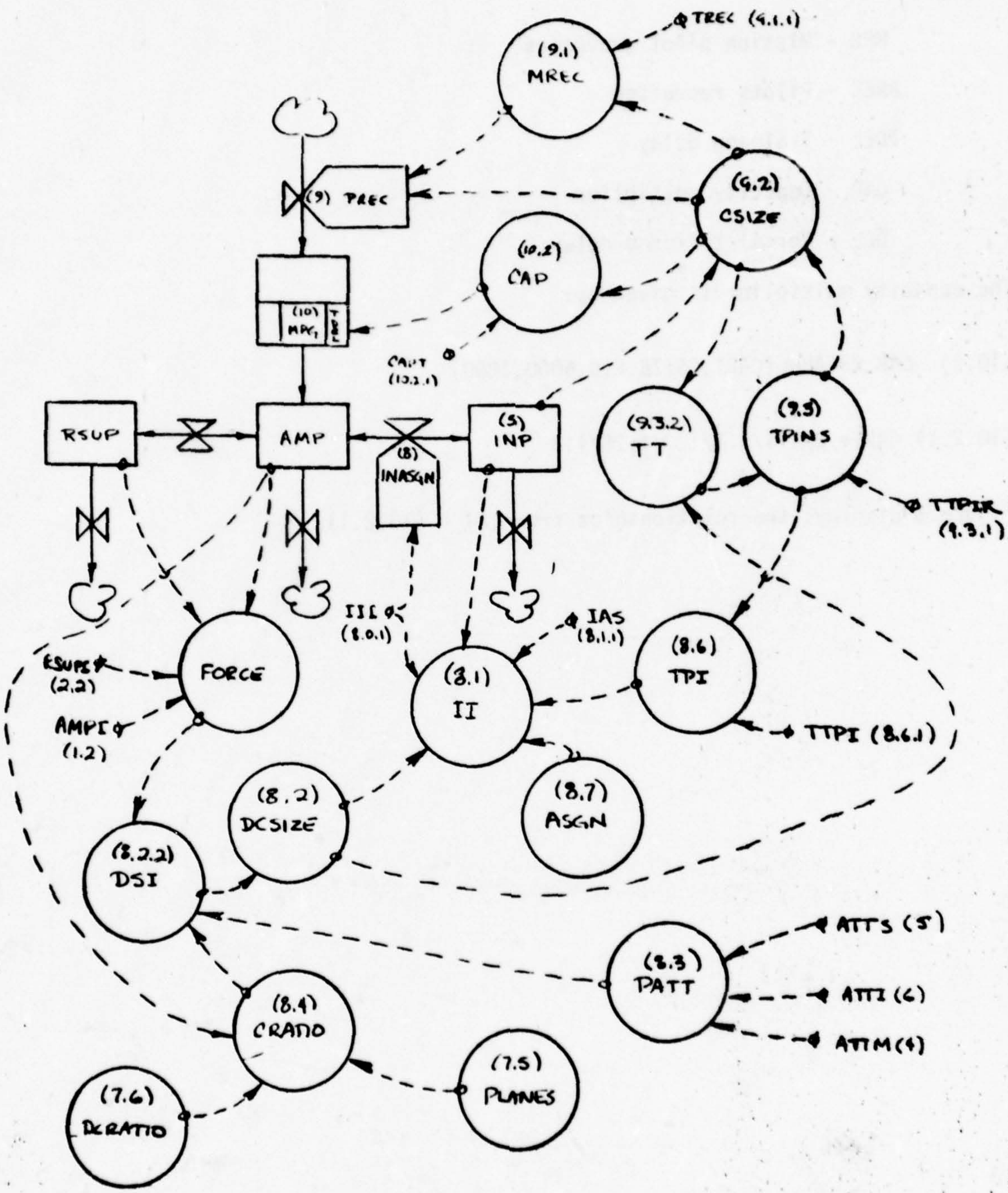

FIGURE 8: COMPUTATION OF PILOTS RECRUITED, INSTRUCTOR ASSIGNMENTS

Chapter 3

Program Listing and Sample Runs

This chapter presents a documented listing of the aggregate pilot pipeline model and a set of program runs. The listing given has the sequence of re-run cards that generates the included output and the control cards for the DYNAMO III F Compiler of the CYBER 74 at ASD Computer Center, Wright-Patterson AFB, Ohio.

```
100=JMF,CM65000,T25,I770010,KNIGHT,53362
110=ATTACH,DYNAMO,DYNAMOL,ID=AFIT,
120=BEGIN,DYNAMO,DYNAMO,CM=65000,
130=*EOR
140=* PILOT PROCUREMENT MODEL
150=NOTE ****************** ****************************************
160=NOTE
170=NOTE
180=NOTE   PILOT PRODUCTION PIPELINE
190=NOTE
200=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
210=R     MPG.KL=DELAY3(PREC.JK,TDEL.K)
220=        MPG    -- MISSION PILOT GRADUATES
230=R     PREC.KL=(CSIZE.K/4)*MREC.K
240=        PREC    -- PILOT CANDIDATES RECRUITED
250=A     MREC.K=TABLE(TREC,CSIZE.K/4,0,1400,200)
260=        MREC    -- MULTIPLIER ON RECRUITING
270=T     TREC=1/1/1/1/1/.95/.89/.82
280=        TREC    -- RECRUITING SATURATION TABLE
290=A     CSIZE.K=INP.K*TPINS.K
300=        CSIZE  -- ANNUAL UPT CLASS SEATS
310=A     TPINS.K=TABHL(TTPIR,TT.K,0,1.75,.25)
320=        TPINS   -- TRAINEES PER UPT INSTRUCTOR
330=N     TPINS=2.4666667
340=T     TTPIR=0/.64/1.28/1.92/2.4666667/3.20/3.6/3.9
350=        TTPIR   -- VARIABLE TPINS RELATIONSHIP
360=A     TT.K=DCSIZE.K/(SMOOTH(CSIZE.K,1))
370=        TT      -- TPINS ADJUSTMENT RATIO
380=A     TDEL.K=CAP.K*DEL
390=        TDEL    -- TRAINING DELAY
400=A     CAP.K=TABLE(CAPT,CSIZE.K,0,6000,1000)
410=        CAP     -- MULTIPLIER ON TDEL FROM CAPACITY UTILIZATION
420=T     CAPT=.8/1/1/1.1/1.2/1.25/1.3
430=        CAPT    -- CAPACITY-DELAY RELATIONSHIP
440=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
450=NOTE
460=NOTE      MISSION PILOTS
470=NOTE
480=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
490=C     TTEST=8
500=FOR I=1,TTEST
510=L     AMP.K=AMP.J+DT*(MPG.JK-INASGN.JK-SUPASGN.JK-ATTM.JK)
520=        AMP     -- ACTIVE MISSION PILOTS
530=R     ATTM.KL=AMP.K*ATTMC*ADMM.K*XTEST.K(1)
540=        ATTM    -- ATTRITION FRM MISSION FORCE
550=A     ADMM.K=TABHL(TAM,FLEV.K,.5,2,.5)
560=        ADMM    -- ATTRITION MANAGEMENT FACTOR
570=T     TAM=.5/1/1.5/2
580=A     FLEV.K=(TOTFOR.K/(TOTFOR.K+FORCE.K))
590=        FLEV    -- FORCE LEVEL ATTRITION ADJUSTMENT
```

```
600=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * *
610=NOTE
620=NOTE        INSTRUCTOR ASSIGNMENT CONTROL
630=NOTE
640=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * *
650=L     INP.K=INP.J+DT*(INASGN.JK-ATTI.JK)
660=        INP      -- INSTRUCTOR PILOTS
670=R     ATTI.KL=INP.K*ATTIC*ADMI.K*XTEST.K(2)
680=        ATTI     -- ATTRITION FROM INSTRUCTOR FORCE
690=A     ADMI.K=TABHL(TAI,FLEV.K,.5,2,.5)
700=        ADMI     -- ATTRITION MANAGEMENT FACTOR: INSTRUCTORS
710=T     TAI=.5/1/1.5/2
720=R     INASGN.KL=CLIP(II.K,MAX(II.K,0),INP.K,III)
730=        INASGN   -- INSTRUCTOR ASSIGNMENT RSTE
740=A     II.K=(DCSIZE.K-CSIZE.K)/(ASGN.K*TPI.K)
750=X     +SMOOTH(ATTI.JK,4)
760=        II       -- INDICATED INSTRUCTOR ASSIGNMENT RATE
770=A     TPI.K=TABHL(TTPI,TPINS.K,1.68,3.44,.44)
780=        TPI      -- INSTRUCTOR ASSIGNMENT COMPENSATION FACTOR
790=T     TTPI=3.44/3/2.4666667/2.12/1.68
800=A     ASGN.K=ASGNDEL*XTEST.K(4)
810=        ASGN     -- ASSIGNMENT DELAY TIME
820=A     DCSIZE.K=MAX(DSI.K,VBL.K)
830=        DCSIZE -- DESIRED UPT CLASS SIZE
840=A     DSI.K=PATT.K+(DCRATIO.K-CRATIO.K)*PLANES.K+FORCE.K
850=        DSI      -- INDICATED UPT CLASS SIZE
860=A     VBL.K=VBLC
870=        VBL      -- UPT VIABILITY LEVEL
880=C     VBLC=400
890=A     FORCE.K=(AMPI+RSUPI-AMP.K-RSUP.K)*XTEST.K(5)
900=        FORCE    -- FORCE DISCREPANCY
910=A     CRATIO.K=AMP.K/PLANES.K
920=        CRATIO -- CREW RATIO
930=A     DCRATIO.K=TABHL(CRT,PHPA.K,0,180,30)
940=        DCRATIO-- DESIRED CREW RATIO
950=T     CRT=0/1.5/2.0/2.5/3.0/3.5/4.0
960=A     PHPA.K=AHOURS.K/PLANES.K
970=        PHPA     -- PROGRAMMED FLYING HOURS PER AIRCRAFT
980=A     AHOURS.K=477000*XTEST.K(7)
990=        AHOURS --AUTHORIZED FLYING HOURS
1000=A    PLANES.K=5300*XTEST.K(6)
1010=       PLANES --TOTAL AIRCRAFT AVAILABLE
1020=A    PILOTS.K=AMP.K+RSUP.K
1030=X    +PMPG.K-(.25*PATT.K)
1040=       PILOTS -- PILOTS AVAILABLE FOR MISSION (PROJECTED)
1050=A    PMPG.K=DLINF3(PREC.JK,PTDEL.K)
1060=       PMPG     -- PROJECTED MISSION PILOT GRADUATES
1070=A    PTDEL.K=SMOOTH(TDEL.K,ST)
1080=       PTDEL    -- PROJECTED TRAINING DELAY IN UPT
1090=C    ST=8
```

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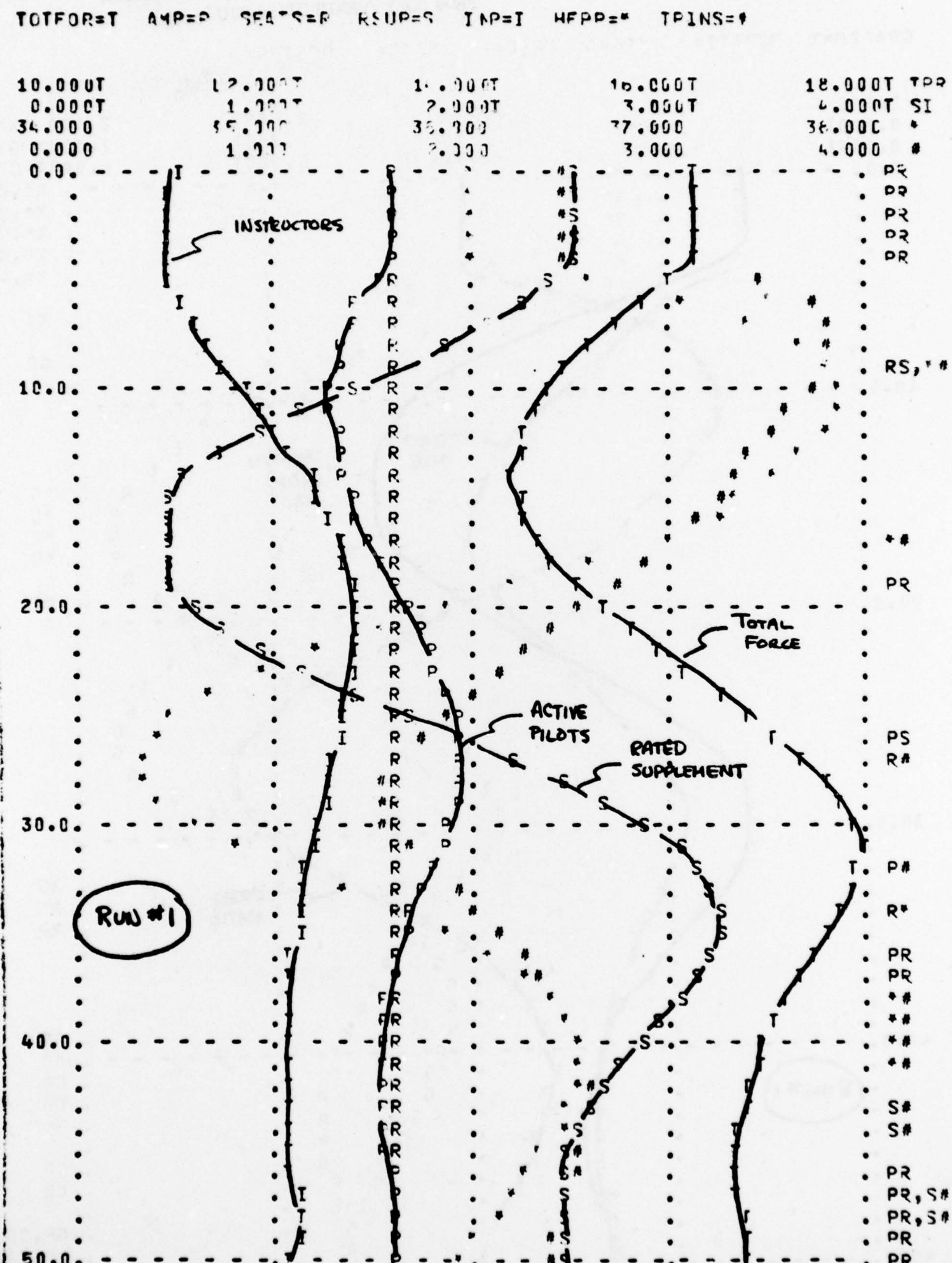
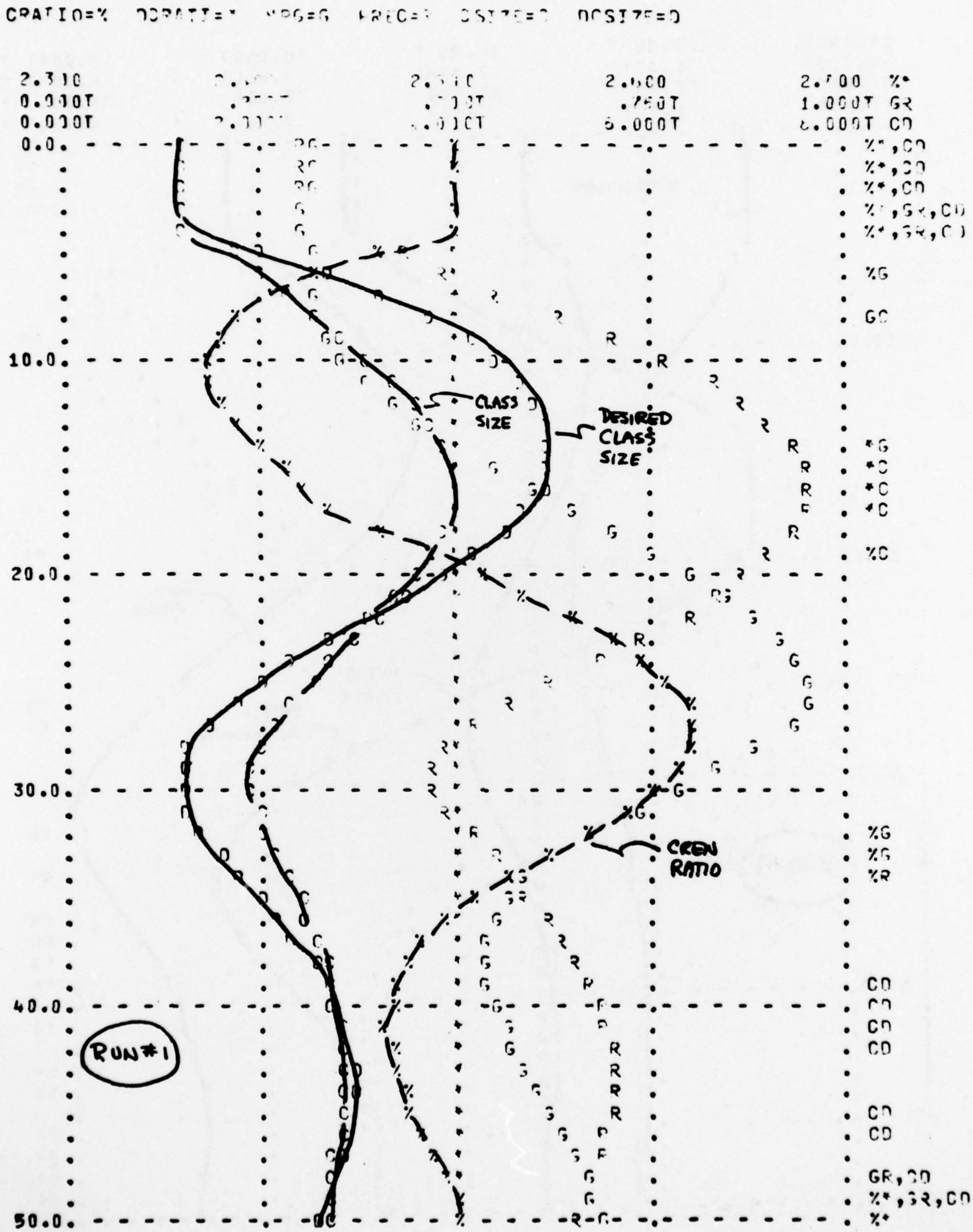
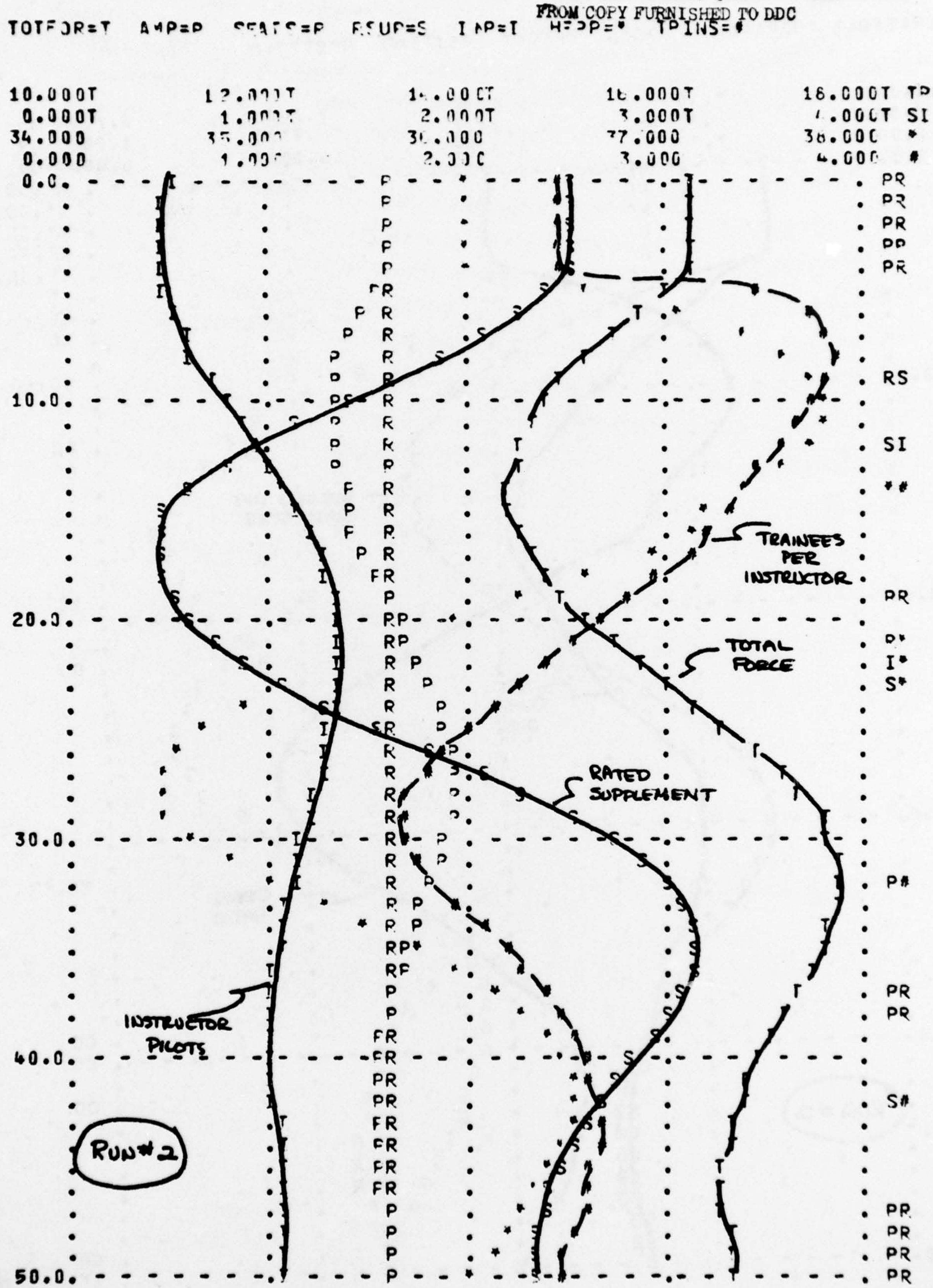
```
1100=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1110=NOTE
1120=NOTE      RATED SUPPLEMENT CONTROL
1130=NOTE
1140=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1150=L    RSUP.K=RSUP.J+DT*(SUPASGN.JK-ATTS.JK)
1160=       RSUP   -- RATED SUPPLEMENT
1170=R    ATTS.KL=RSUP.K*ATTSC*ADMS.K*XTEST.K(3)
1180=       ATTS   -- ATTRITION FROM RATED SUPPLEMENT
1190=A    ADMS.K=TABHL(TAS,FLEV.K,.5,2,.5)
1200=       ADMS   -- ATTRITION MANAGEMENT FACTOR: SUPPLEMENT
1210=T    TAS=.5/1/1.5/2
1220=A    SEATS.K=PLANES.K*DCRATIO.K
1230=       SEATS  -- FLYING SLOTS AVAILABLE
1240=A    DRTSUP.K=PILOTS.K-SEATS.K
1250=       DRTSUP -- DESIRED RATED SUPPLEMENT
1260=R    SUPASGN.KL=CLIP(SS.K,MAX(SS.K,0),RSUP.K,SSS)
1270=       SUPASGN-- ASSIGNMENT RATE TO SUPPLEMENT
1280=A    SS.K=((DRTSUP.K-RSUP.K)/ASGDEL)+SMOOTH(ATTS.JK,4)
1290=       SS      -- INDICATED ASSIGNMENTS TO SUPPLEMENT
1300=A    PATT.K=4*SMOOTH(ATTI.JK+ATTM.JK+ATTS.JK,4)*XTEST.K(8)
1310=       PATT    -- PROJECTED PILOT ATTRITION
1320=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1330=NOTE
1340=NOTE      TEST INPUTS, INITIAL CONDITIONS, AND CONSTANTS
1350=NOTE
1360=NOTE * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1370=C    SSS=500/III=200
1380=C    ASGNDEL=8/ASGDEL=3
1390=C    ATTIC=.02/ATTMC=.02/ATTSC=.0133333
1400=A    XTEST.K(I)=1+STEP(SH(I),SST(I))+NN(I)*SMOOTH(NOISE(),NST(I))
1410=X     +APL(I)*SIN(6.284*TIME.K/PER(I))
1420=X     +RAMP(RS(I),RST(I))-RAMP(RSS(I),RSTS(I))
1430=NOTE *******TEST VARIABLES*******
1440=NOTE          1:ATTM
1450=NOTE          2:ATTI
1460=NOTE          3:ATTS
1470=NOTE          4:ASGN
1480=NOTE          5:FORCE
1490=NOTE          6:PLANES
1500=NOTE          7:AHOURS
1510=NOTE          8:PATT
1520=NOTE ***************************
```

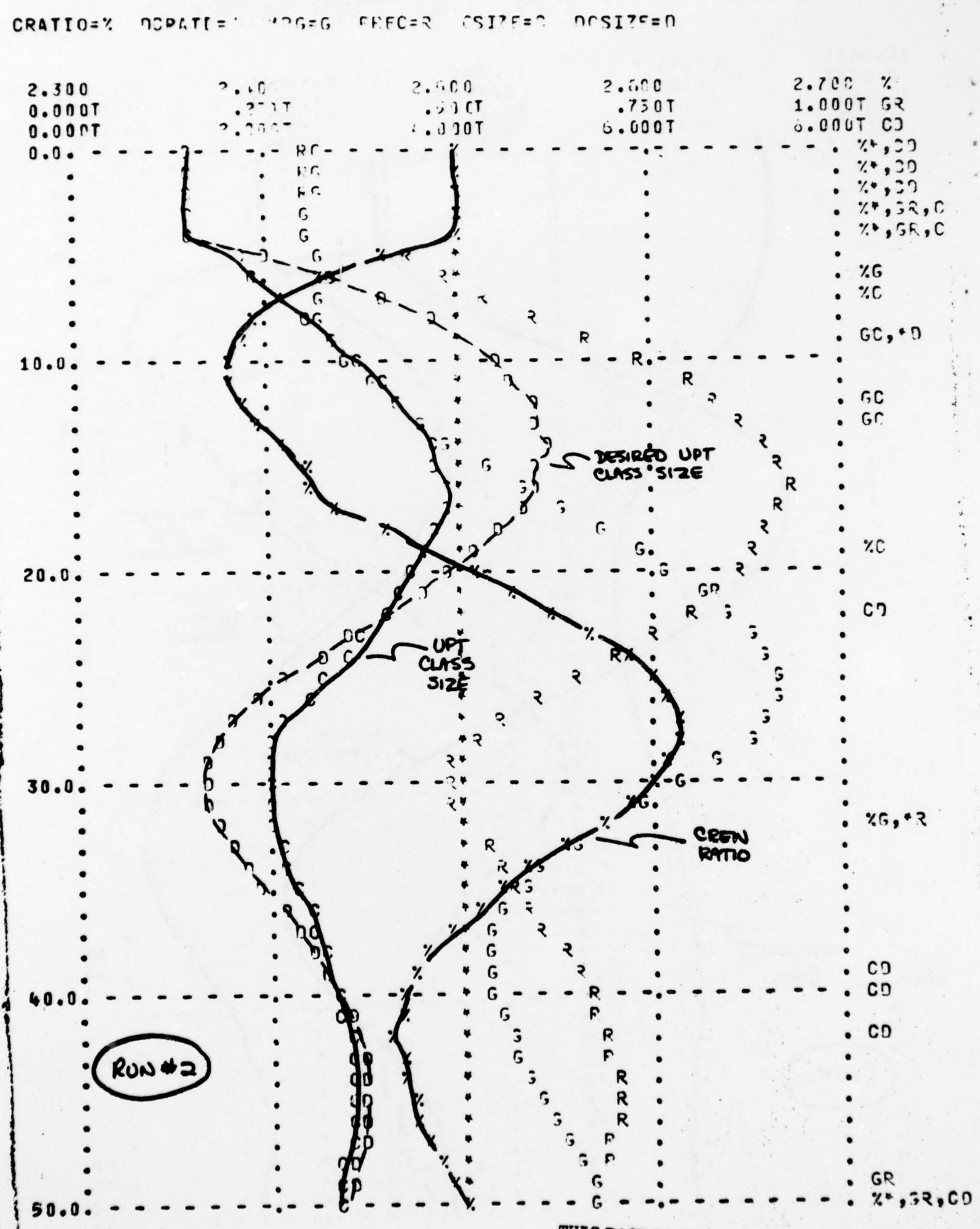
```
1530=T    SH=0/0/0/0/0/0/0/0
1540=T    SST=4/4/4/4/4/4/4/4
1550=T    NN=0/0/0/0/0/0/0/0
1560=T    NST=4/4/4/4/4/4/4/4
1570=T    APL=0/0/0/0/0/0/0/0
1580=T    PER=20/20/20/20/20/20/20/20
1590=T    RS=0/0/0/0/0/0/0/0
1600=T    RST=4/4/4/4/4/4/4/4
1610=T    RSS=0/0/0/0/0/0/0/0
1620=T    RSTS=20/20/20/20/20/20/20/20
1630=C    DEL=7
1640=N    AMP=AMPI
1650=N    INP=INPI
1660=N    RSUP=RSUPI
1670=C    AMPI=13250/INPI=500/RSUPI=2500
1680=A    HFPP.K=AHOURS.K/AMP.K
1690=A    TOTFOR.K=AMP.K+RSUP.K+INP.K
1700=PLOT TOTFOR=T,AMP=P,SEATS=R/RSUP=S,INP=I/HFPP=*/TPINS=#
1710=PLOT CRATIO=%,DCRATIO=*/MPG=G,PREC=R/CSIZE=C,DCSIZE=D
1720=SPEC  DT=.25/LENGTH=50/PLTPER=1
1730=RUN   DEBUG
1740=*EOR
1750=T  SH=1/1/1/0/0/0/0/0
1760=RUN
1770=TP NN=1/1/1/0/0/0/0/0
1780=RUN
1790=TP TTPI=3/2.5/2.4666667/2.42/2
1800=RUN
1810=T  SH=1/1/1/0/0/0/0/0
1820=T  NN=0/0/0/0/0/0/0/0/0
1830=RUN
```

Four runs of the model are included. Run 1 shows the response of the model to a step increase in attrition from the pilot force from two percent to four percent per quarter. Fun 2 shows the step response under a modified management policy which slows the movement of pilots into the instructor force. Run 3 imparts a uniform autocorrelated pink noise input into the attrition rates. Run 4 does the same with the modified management policy. These run plots given represent the forced particular solution to the equations of the model under a given set of initial conditions.

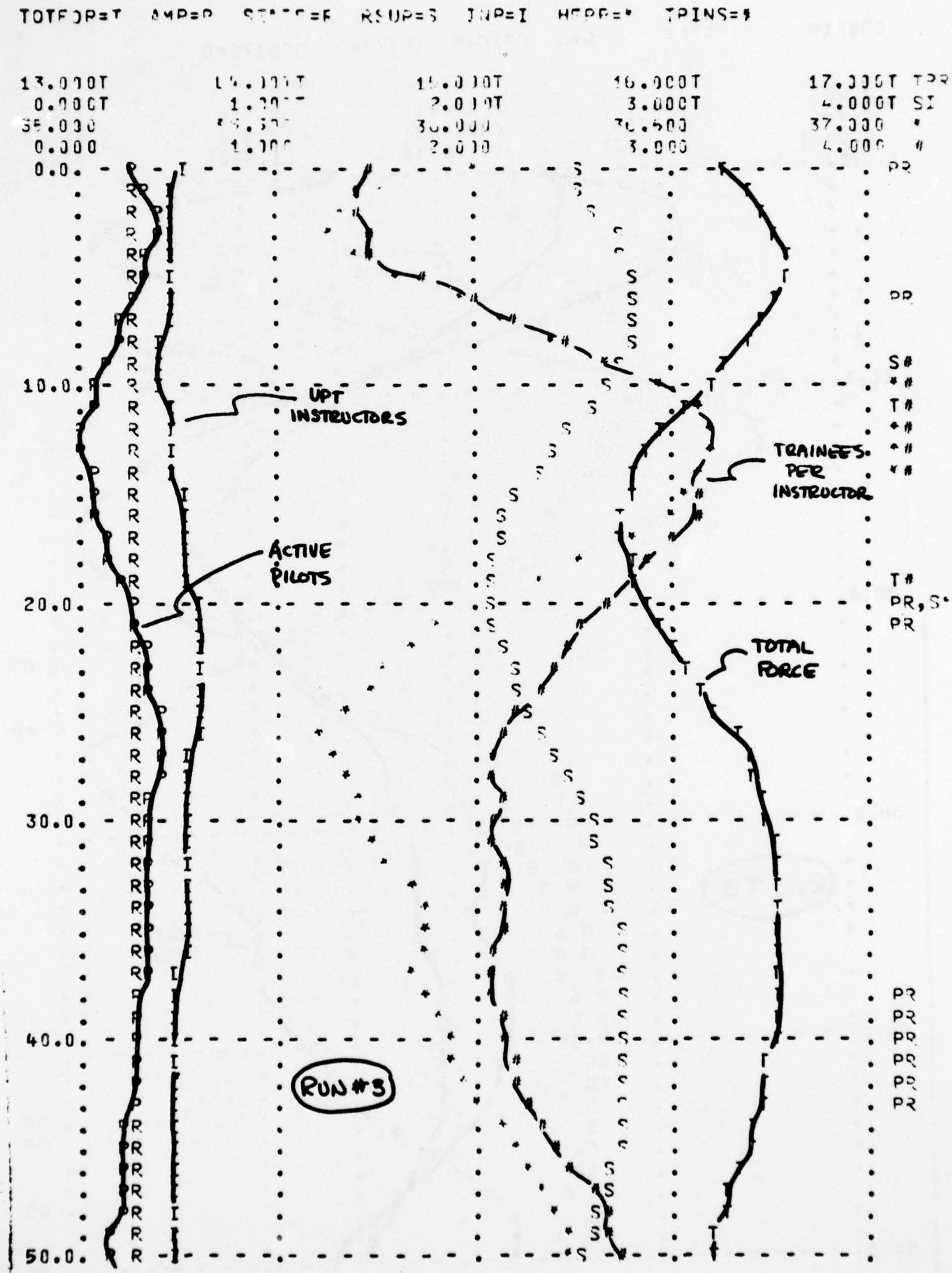

TOTFOR=T AMP=P SEATS=R RSUP=S INP=I HEPP=* TRINS=#
10.000T 12.000T 14.000T 16.000T 18.000T TPR
0.000T 1.000T 2.000T 3.000T 4.000T SI
34.000 35.000 36.000 37.000 38.000 *
0.000 1.000 2.000 3.000 4.000 #
0.0
10.0
20.0
30.0
40.0
50.0
INSTRUCTORS
TOTAL FORCE
ACTIVE PILOTS
RATED SUPPLEMENT
RUN #1


2.310
0.000T
0.000T
2.600
.750T
6.000T
2.700
1.000T GR
6.000T CD
0.0
10.0
20.0
30.0
40.0
50.0
CLASS SIZE
DESIRED CLASS SIZE
CREN RATIO
RUN#1


TRAINEES PER INSTRUCTOR
TOTAL FORCE
RATED SUPPLEMENT
INSTRUCTOR PILOTS
RUN#2



CRATIO=% DSRATE= MRG=G FREC=R CSIZE=C DCSIZE=D
2.300
0.000T
0.000T
1.000T GR
6.000T CD
.750T
6.000T
0.0
10.0
20.0
30.0
40.0
50.0
DESIRED UPT CLASS SIZE
UPT CLASS SIZE
CREW RATIO
RUN #2


13.000T
0.000T
35.000
0.000
15.000T
2.000T
2.000
16.000T
3.000T
3.000
17.000T
4.000T
37.000
0.0
10.0
20.0
30.0
40.0
50.0
UPT INSTRUCTORS
ACTIVE PILOTS
TRAINEES PER INSTRUCTOR
TOTAL FORCE
RUN #3

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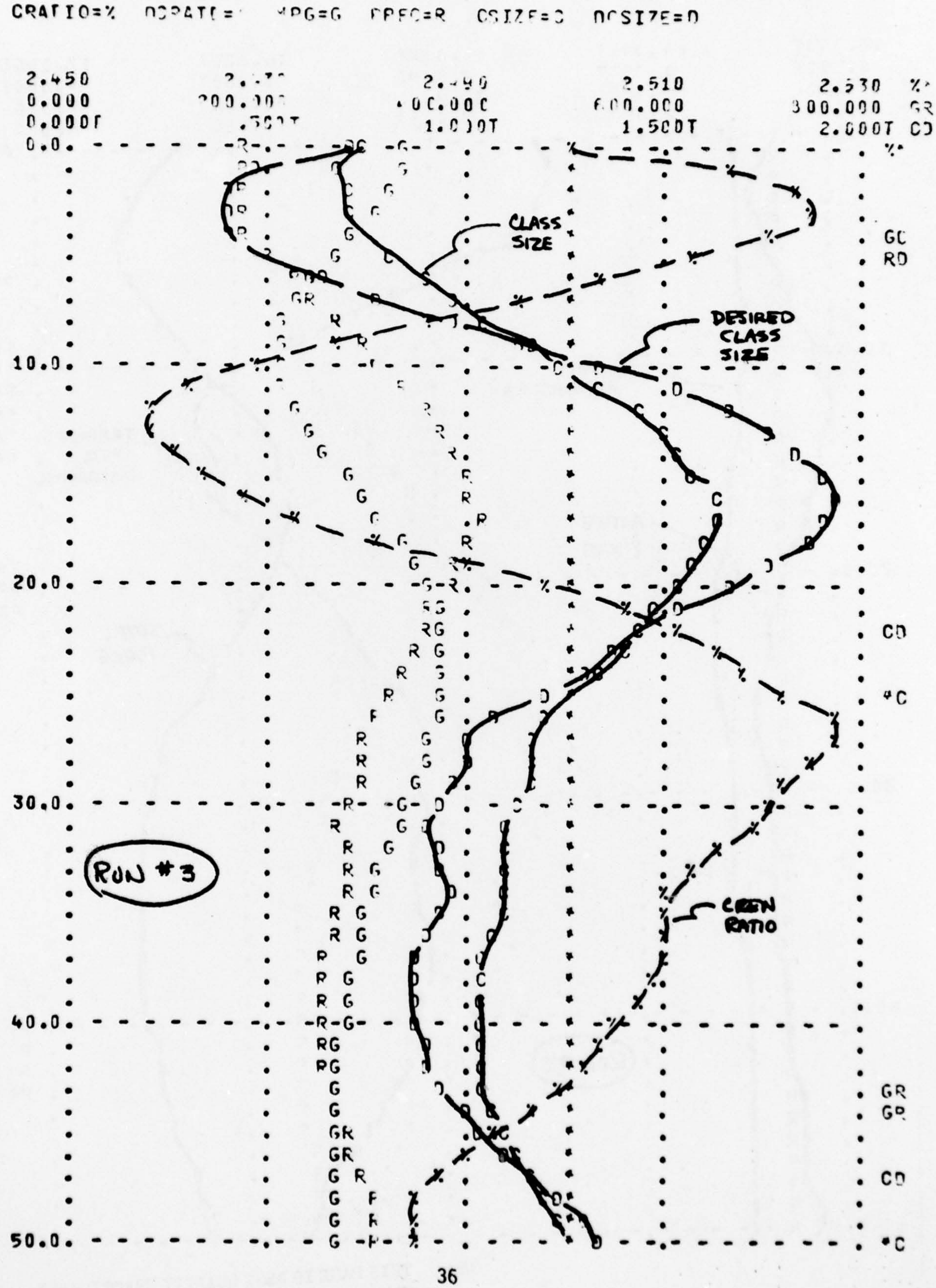

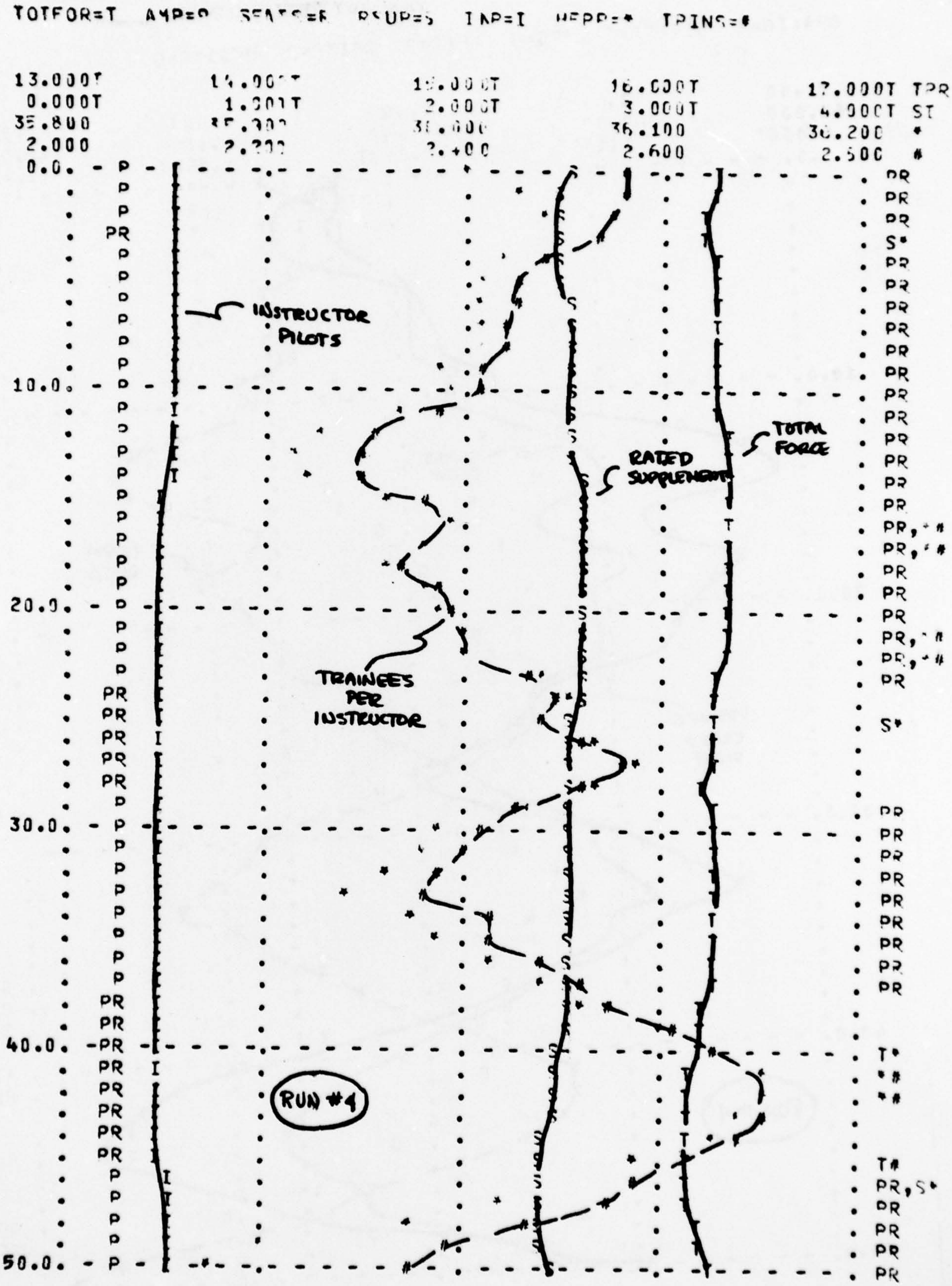
INSTRUCTOR PILOTS
TOTAL FORCE
RATED SUPPLEMENT
TRAINEES PER INSTRUCTOR
RUN #4

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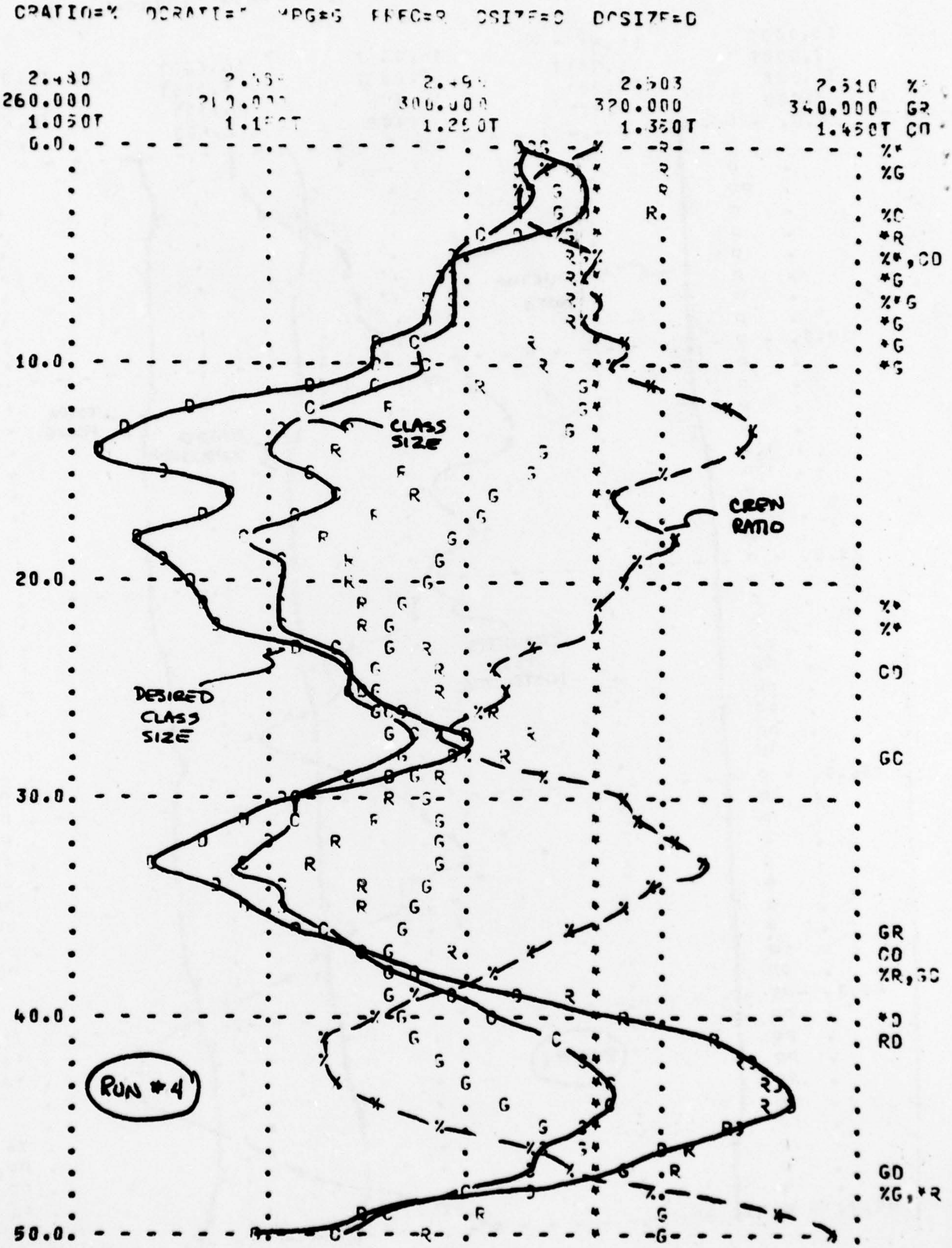

(1) Forrester, Jay W., Principles of Systems, Second Preliminary Edition, Wright-Allen Press, Inc., 1968.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Simulation
Manpower Systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This technical report documents the structure of an aggregate representation of a system which governs the recruitment, training, and allocation of Air Force pilots. While the model is highly simplified, it captures many of the essential policies and decisions which generate the dynamic behavior of the overall system. Specifically, the model takes as given the authorized flying hours and aircraft available to the Air Force; it combines these data with information about projected strngth levels in the pilot force to determine training requirements. These training requirements are used to establish the

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requirements for Undergraduate Pilot Training (UPT) instructors and recruiting quotas. The model then allocates the existing force among three categories: (1) the active mission force, (2) UPT instructors, (3) the rated supplement. The model can be used to examine such things as overall policies controlling UPT class size, and allowable limits of variation on the UPT instructor to student ratios. It also can be used to test the sensitivity of system adjustment process to exogenous impacts.